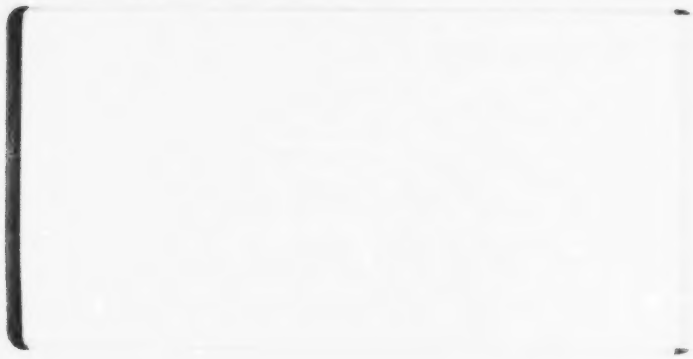


CONTRACT SERIAL NUMBER OSR81-00045

CONTRACTOR: Williams Brothers Canada Ltd.

CONTRACT REQUISITION NO. 23440-1-9006

DEVELOPMENT OF A COMPUTER CONTROL SYSTEM FOR A HEAVY MEDIA COAL PROCESSING PILOT PLANT

Final Report, February 1986

Prepared by:
DATAP SYSTEMS, A Division of
Swan Wooster Engineering Co. Ltd.
#202, 1167 Bowness Road N.W.
Calgary, Alberta
Canada

Prepared for:
Energy, Mines and Resources (EMR)
Ottawa, Ontario
Canada

OCT 14 1986
MICROMEDIA

31 pp

Project/Contract #OSR81-00045

DATAP SYSTEMS

TABLE OF CONTENTS

ABSTRACT

NOTICE

1. INTRODUCTION
   - 1.1 Background
   - 1.2 Project Objective

2. THE COAL PREPARATION PROCESS
   - 2.1 The Heavy Medium Coal Preparation Process
   - 2.2 Mechanical Configuration
   - 2.3 Instrumentation

3. PROCESS CONTROL
   - 3.1 Control Philosophy
   - 3.2 Cone Control Algorithm
   - 3.3 Water Control DDC Algorithm

4. THE COMPUTER CONTROL SYSTEM
   - 4.1 Control System Hardware
     - 4.1.1 Micromaster
     - 4.1.2 Operator Console
     - 4.1.3 Logger
     - 4.1.4 Inter CPU Communications
   - 4.2 Control System Software
     - 4.2.1 Operating System
     - 4.2.2 Parallel Input-Output
     - 4.2.3 Operator Interface
     - 4.2.4 CRT Displays

Table of Contents cont'd

5. CONCLUSIONS & RECOMMENDATIONS

FIGURE 1 Heavy Medium Control Flowsheet
FIGURE 2 The Concept of Zone Control
FIGURE 3 Computer System Structure
FIGURE 4 Menu Page
FIGURE 5 Alarm Page
FIGURE 6 Analog Page
FIGURE 7 Circuit Diagram
FIGURE 8 System History Page
FIGURE 9 Status Page
FIGURE 10 Real Time Test Results
FIGURE 11 Real Time Test Results

DATAP SYSTEMS

NOTICE

Neither the Crown nor EMR makes any representations with respect to the accuracy, completeness, or usefulness of the information contained in the report nor assumes any liabilities with respect to the use of, or damages resulting from the use of, any information, apparatus, method or process disclosed in the report.

ABSTRACT

This report describes the development of a microcomputer based density control system for a heavy media coal preparation pilot facility at the Edmonton Coal Research Laboratory. The highly complex process dynamics, coupled with a long system time delay, render the application of conventional PI or PID control unsuitable. A control system based on the concept of control zone and a pulse amplitude modulation technique for diversion cone positioning have been implemented. Preliminary testing indicates that the control system remain stable under steady state operating conditions. Moreover, a density set point with fluctuation within a tolerance of ±0.005 can be achieved. Step response with respect to set point changes has been satisfactory.

DATAPSYSTEMS

SECTION 1
INTRODUCTION

1.1 BACKGROUND

The Edmonton Coal Research Laboratory (ECRL) of CANMET, along with other research organizations in coal producing countries, have envisaged major benefits of computer automation in coal preparation. The application of computer automation provides greater system flexibility, improved coal preparation plant efficiency and efficient utilization of manpower. Consequently, major economical benefits are achieved as a direct result of the usage of computer automation.

The coal research laboratory operates a 10 ton/hr versatile pilot plant facility. One of the methods of coal preparation utilized in the pilot plant facility is the heavy media type. This pilot plant is being used for the development of control schemes for different process, first independently and later on integrated process control systems.

The advantages of using the pilot plant for process control development are:

1. Minimize cost, and in turn, risk of the development.

2. Flexibility in installing, testing and if necessary, system modification during the development phase.

3. Last but not least, flexibility in time during testing that is not feasible at an operating plant.

DATAP SYSTEMS

1.2 PROJECT OBJECTIVE

The main objective of the project is to design and implement a complete computer control system for the ECRL coal preparation pilot plant. This includes such aspects as precise definition of system requirements, literature surveys, conceptual and detailed system design, selection and procurement of control system elements, design and preparation of microprocessor softwares, preparation of installation drawings, limited installation start-up assistance and final documentation.

DATAP SYSTEMS

SECTION 2
THE COAL PREPARATION PROCESS

2.1 THE HEAVY MEDIUM COAL PREPARATION PROCESS

Figure 1 illustrates a conceptual flowsheet and design material balance for the heavy media coal preparation pilot facilities. The process treats coal by submerging the raw coal into a liquid or media suspension that has a specific gravity intermediate between the coal and the mineral impurities. Magnetite is most frequently used because of its low cost and the ease with which it can be recovered by magnet.

Raw coal could be fed by means of a conveyor into the heavy medium feed tank in which it is mixed with the correct heavy medium. From the heavy medium feed tank, it is pumped into a heavy medium cyclone. In a typical heavy medium cyclone, a mixture of medium and deslimed raw coal enters tangentially near the top of the cyclone section. Due to strong centrifugal action, the clean coal, being of lower specific gravity, is found towards the axis of the cyclone while the mineral material matter or shale (being of higher specific gravity), is forced towards the walls of the cyclone. The clean coal, collected at the central axis of the cyclone, exits at the top while the mineral matter or shale is discharged from the bottom of the cyclone.

The separated products, coal and shale, are discharged on two vibrating screens after leaving the cyclone. Under each screen, two fluid receivers are placed. The first of which collects the undiluted suspension and the suspension are returned to the heavy media feed tank via a 4-way distributor box. The second receiver collects the rinsing water enriched with the suspension washed off the second part of the screen and deposits them into

DATAP SYSTEMS

the dilute medium tank. By recirculating the diluted media through a magnetic separator, the magnetite is recovered and fed back into the heavy medium loop.

2.2 MECHANICAL CONFIGURATION

The flowsheet of the installed system for controlling the medium density, which is shown in Figure 1, is designed to achieve accurate density measurement and control. The main features of the installed system are:

a) A 4-way distributor box which has four outputs (Figure 1, No. 6 in circle):
   - a flow for density measurement
   - a flow for direct addition to heavy medium feed tank
   - a flow for addition with the raw coal into the Heavy Medium Feed tank central tube
   - a control flow to the density control cone;

b) Air bubbles are eliminated in the gravity drop density measurement pipe via a full distributor compartment providing full pipe flow (Figure 1, No. 5 in square);

c) A heavy medium feed tank with a central tube to provide proper mixing of the deslimed coal and medium. The tube directs the lower density coal into the vortex of the tank outlet to pump suction (Figure 1, No. 1 in circle);

d) Automatic, continuously modulating density control cone for primary density control. This device diverts the required percentage of medium to the magnetic separator (or dilute medium loop) for density control and bypass the

DATAP SYSTEMS

remainder to the heavy medium feed tank (Figure 1, No. 6 in square);

e) Automatic, on/off control valve for water addition to the heavy medium circuit (Figure 1, No. 8 in square);

f) Remote manual on/off control for a vibrating belt type Fe304 feeder. The feed rate is adjustable from 0 to 5 tons per hour (Figure 1, No. 4 in square);

g) A dilute medium tank and circuit (with magnetic separator) for material balance and magnetite recovery. Level control for the dilute medium tank via an automatic on/off modulating control cone (Figure 1, No. 7 in square).

2.3 INSTRUMENTATION

Process Control Instrumentation used includes:

a) Heavy medium (H.M.) and dilute medium tanks continuous level monitor with high/low level alarms via computer interface and control. A flange mounted differential pressure unit mounted on the side of the tank at the low level point is used (Viatran 504). It uses direct electronic sensing of pressure variations on an exposed isolating diaphragm to measure changes in tank level. Accuracy is ±0.25% of calibrated span (Figure 1, No. 1 and 2 in square);

b) Densitometer - A non-contact nuclear density gauge unit clamped to the gravity drop density measurement pipe and also supported from the distributor box stand provides continuous density measurement of accuracy ±1% of span (which can be as slow as 0.200 specific gravity units

(SGU) giving an accuracy of 0.002 SGU) (Texas Nuclear SGH, Model 5190 source head and model 5359 detector). A 4-20 mA output proportional to span is interfaced with the master computer to maintain set point density (Figure 1, No. 5 in square). The gravity drop density measurement pipe is assured of being full at all times by the 50mm to 25mm pipe reducer below the measurement location.

c) Flowmeter - A doppler style flowmeter is used to measure the flowrate of the cyclone feed, and has accuracy of 1% of calibrated span (Figure 1, No. 3 in square).

d) Magnetite Bin Feeder/Vibrator - A vibrator mounted on the side of the 0.28 m^3 hopper and a second vibrator on the pan feeder below can be manually controlled for adjustable feed rates from 0 to 100% capacity of 4.5 to 13.6 kg/h. Dribble and fast feed rates are available. This unit can be remotely stopped or started through an operator request at the computer (Sepor model FRV-413) (Figure 1, No. 4 in square).

e) A modulating pneumatic cylinder positions the density control cone over the two compartment distributor divider in proportion to the 4-20 mA control signal initiated by the Direct Digital Control (DDC) algorithm. This provides the fine density control with proportional distribution to the magnetic separator for excess water or magnetite removal (Figure 1, No. 6 in square). A similar on/off type unit is used for dilute medium tank level control (Figure 1, No. 7 in square).

f) An open/close solenoid valve activated via the master computer density control algorithm adds water to the H.M. circuit as required. The cycle and the shape of the cycle

DATAP SYSTEMS

(on-off) are adjustable (Figure 1, No. 8 in square). All instrumentation is wired to the control room in the pilot plant and interfaced with the master computer. Analog outputs are 4-20 mA. Electrical power used is 115V, 1 phase, 60 cycle with special power supplies incorporated with instrumentation controls where required.

DATAR SYSTEMS

SECTION 3

PROCESS CONTROL

3.1 CONTROL PHILOSOPHY

Primary density control is provided by a continuously modulating cone that diverts the required percentage of medium to the dilute medium loop such that medium density can be increased by effectively removing a certain amount of water from the heavy medium loop. Also, the controller algorithm allows the density to be reduced by timed addition of water via an on/off valve.

Magnetite is added when required during a run; the operator console allows addition if required.

A nuclear density gauge is used to measure the medium density, and the density reading compares with the cutpoint in the density control algorithm to generate the error signal to be utilized in the DDC algorithm.

The level in the dilute medium tank is also controlled by a pneumatic cone. If the tank level is too high, some of the magnetic separator underflow is diverted to the slimes tank, in turn causing the level in the dilute medium tank to drop.

To increase or decrease the density of the heavy media curcuit, the concept of applying zones for different control action has been developed.

Figure 2 illustrates the concept of using zone control. Basically, the control domain is divided up into three zones or regions. They are:

a) Water control zone. The error region in which water control will take effect.

b) Cone control zone. The error region in which cone control will take effect.

c) Cone control deadband. The error region in which neither the cone control nor the water control will take effect.

3.2 CONE CONTROL ALGORITHM

Due to the fact that material balance can be achieved at a specific cone position, a pulse amplitude modulation technique has been implemented for cone positioning control. The advantage of using this type of control action is that the controller designed is of a cautious nature.

Definitions:

Error, ε	Density $_{sp}$ - Density measured
ΔU	Percentage change in cone control output w.r.t. the equilibrium cone position.
U_E	Equilibrium Cone Position
U_C	Current cone o/p position
t_p	density control time period
t_w	cone control o/p pulse width

Strategy:

If $|\varepsilon| \leq$ Cone Control deadband

$U_C = U_E$ for $t = t_p$

If Cone Control deadband $\leq |\varepsilon| \leq$ water control deadband

If ε is positive

$U_C = U_E + \Delta U$ for $t = t_w$
$U_C = U_E$ for $t = t_p - t_w$
end if
else if ε is negative
$U_C = U_E - \Delta U$ for $t = t_w$
$U_C = U_E$ for $t = t_p - t_w$
end if

If $|\varepsilon|$ lies in the water control region, water control take effect.

$\Delta U = k * |\varepsilon| *$ scaling factor
k = Pulse amplitude modulation gain

3.3 WATER CONTROL DDC ALGORITHM

For water control, a velocity type algorithm with two-mode control (proportional + integral) will be used. The advantages of a velocity algorithm are:

a) changes in the set point do not give a kick to the system; and
b) reset windup does not occur.

The equation is:

$$V_{out} = \sum \Delta V$$

$$\Delta V = K_1 * (M_n - 1 - M_n) + K_2 * \frac{\Delta t}{60} (SP - M_n)$$

$$K_1 = K * KG$$

$$K_2 = K * KG * KR$$

ΔV = change required in controller value (for the pneumatic cones, change in cone position; for water value, change in % open time)

K = pre-scaler

KG = proportional gain (100% proportional band)

KR = integral gain

Mn = measured variable

SP = setpoint

Δt = DDC time period (sec)

Since the setpoint occurs only in the integral term, the integral gain should never be set to 0.

More difficult processes with slower response times are best controlled by a modified equivalent PI control law of the form;

$$\Delta V = K_1(M_n^* - M_n) + K_2 * \frac{\Delta t}{60}(SP - M_n)$$

where M_n^* = measurement sampled shortly before M_n.

In fast control loops (on/off water addition), where the control law is calculated every sampling period, M_n^* is the same as M_{n-1}. However, in slow and more difficult control loops, M_n^* would be the latest sample value previous to the control sample M_n. Thus the control sampling period may be considerably longer than the input sampling period. A digital filter provides for density measurement to reduce the effects of noise. It averages the input samples during one filter period. The equation is:

$$Y = \frac{1}{N} \sum_{i=1}^{N} X_1$$

where

Y = filter output

X = filter input (density measurement)

N = # of input sample in one filter period

Lags and Dead Times

Special consideration must be given to system responses in this circuit because of the large time constraints that exist.

System capacity, flow velocities and piping configuration have been used to estimate the dead time and time constant to be approximately 1 minute and 2 minutes, respectively, for the pneumatic cone density control loop.

Technically, the proper control sampling time to use for a given control loop is a function of the process dynamics and the control law used. In the dead time plus lag process, the best performance is usually at a control sampling period approximately equal to the overall process time constant. However, the overall time constant of the density control system is long (1 min.) for the pneumatic cone density loop. A control period of that length would be extremely sluggish in responding to set-point changes.

Thus a shorter period (30 sec.) is attempted with lower gains in the controller. The on/off water valve on the other hand has a much quicker response time period (10 sec. initially).

The controller sampling periods are easily adjusted to arrive at the best performance. To provide more intimate control in emergency or shutdown situations manual override is available for all controllers.

SECTION 4
THE COMPUTER CONTROL SYSTEM

4.1 CONTROL SYSTEM HARDWARE

4.1.1 Micromaster

The centre of the control system is a WESDAC M2 Micromaster based on the MOTOROLA M6809 microprocessor and consisting of two types of printed circuit boards (Figure 3).

The main board contains the CPU, memory (EPROM, RAM), clock and logic circuits, parallel input-output interface, 9 serial asynchronous communication ports, and an arithmetic processor.

The second board is a WESDAC M1 operating strictly as a slave used for input and output. It is equipped for 40 status/alarm inputs, 16 open collector control outputs, 16 analog inputs, 2 analog outputs, and 4 accumulator inputs.

Power supplies with the micromaster allow operation from standard 110 VAC.

4.1.2 Operator Console

The operator console is a CRT with a standard green/black screen with 24 x 80 fonts. It has limited graphics capability for picture drawing.

The micromaster communicates with the CRT at 9600 baud over one of the serial ports. All displays and operator dialogue are via the operator console.

DATAP SYSTEMS

4.1.3 Logger

The micromaster outputs status/alarm messages and the operators log to a printer operating at 180 characters per second.

4.1.4 Inter-CPU Communications

The micromaster is required to pass various parameters to an HP9845 desk top computer. This is done via one of the serial asynchronous communications ports. RS232 to HPIB translation is done by an HP98036A serial interface. The HP9845 has an extra HPIB port. HP9845 application software can easily obtain the parameters.

4.2 CONTROL SYSTEM SOFTWARE

4.2.1 Operating System

Application software executes under RT69, a highly responsive event driven multiprogramming operating system designed for real-time process control, communications and information management systems.

RT69 is the software framework that allows available resources (memory, CPU time, and peripheral devices) to be shared by several tasks. A task is a portion of machine code that performs a specific function; a task is defined by convention since it overlaps with the definitions of "program" and "subroutine". A priority scheme establishes the relative importance of various tasks in the system. This allows a less important task to be interrupted to permit execution of a time critical task. For RT69, a fixed priority scheme is used to reduce scheduling overhead.

4.2.2 Parallel Input-Output

All field devices are driven from the input and output sections on the slave WESDAC board. The software controls this I/O via a parallel input-output bus interface. The Peripheral BUS Handler subroutines perform all input and output operations on the peripheral data bus.

Control output function operates relays according to a mask table (1 = energized, 0 = de-energized) and a timer table in the database. Any task may operate a relay by modifying these tables.

Analog output function periodically outputs the current raw counts to each D/A converter. It can provide output ramping if required.

The analog input function multiplexes 16 analogs in through the A/D converter and stores the raw value for processing. The scan rate for each analog is adjustable.

The status input task reads the field state of each status/alarm point and stores it in the database.

4.2.3 Operator Interface

The devices and program modules which facilitate exchanges of information and requests between operator and the field comprise an important and major aspect of the computer automation system. They are broadly referred to as the "Operator Interface". The role of this interface is to present data and information to allow the operator to enter data and parameters that control the field as desired. These interactions betwen the operator and the computer must be conducted in a comprehesive, concise, logi-

cal and error-forgiving manner so the operator may maintain a continuous, intimate awareness of these heavy media circuit operating conditions. This awareness should be available with little regard for the intervening activities of the computer system.

The operator interface is composed of a green/black CRT and a logger. The CRT is used for both displays and operator input to the system.

4.2.4 CRT Displays

The operator's console is a standard green/black CRT primarily used for the circuit diagram. There are several displays available to the operator consisting of both alphanumeric pages containing status, alarm, analog information and a pictorial schematic of the circuit. The general format of all pages is identical. The top line is reserved for the date, time and page title. The bottom line is reserved for operator dialogue. The second from the bottom line may be used to display the most recent event that has been logged. In between is the display area. While present on the screen, a display page will be periodically refreshed with updated data. A hard copy of all pages except the circuit diagram may be obtained on the printer. The different pages are shown in Figures 3-8.

DATAP SYSTEMS

SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

Due to the highly complex nature of the plant dynamics, the initial application of PI control for cone positioning has been abandoned in favour of a pulse amplitude modulation control technique. Test results have shown that with the cone position operating at other than 30° diversion (system equilibrium position), the density of the medium will either increase or decrease continuously, i.e., the cone position determines the rate of density changes rather than raising or lowering it to a proportional value. The application of the conventional linear control technique such as the PI or PID control is therefore inappropriate.

Preliminary trial runs of the implemented control algorithms have been satisfactory. In automatic control mode, the desired setpoint can be maintained within a fluctuation of ±0.005 at steady state operations (refer figures 10 & 11). We do not foresee the control loop to operate erratically under steady state conditions.

This can be substantiated by the fact that instability has not been observed over a test run period of 4-6 hours.

Tests have also been conducted with respect to setpoint changes. At present, the controller can be tuned to exhibit a step response of approximately 8-10 minutes. We believe that the response time can further be improved by fine tuning the gain of the controller and the density control time period.

Further tests are warranted to facilitate a complete evaluation of the suitability of the implemented algorithms. This includes operating the pilot plant with raw coal feed.

At present, the pulse amplitude modulation control uses a linear gain strategy. The possibility of incorporating a non-linear gain with higher gain factor at small density error be further investigated.

Moreover, the potential of using a more advanced control technique such as optimal control strategy or self-tuning control approach are to be evaluated.

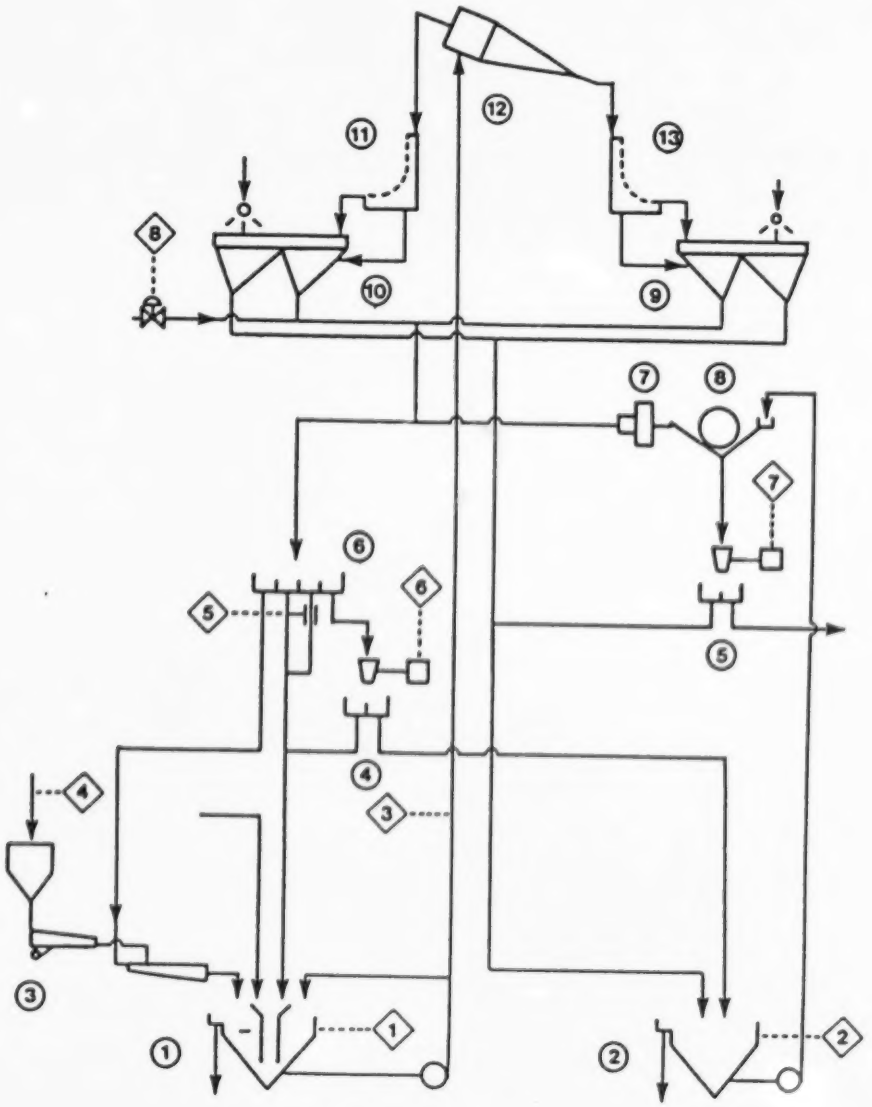
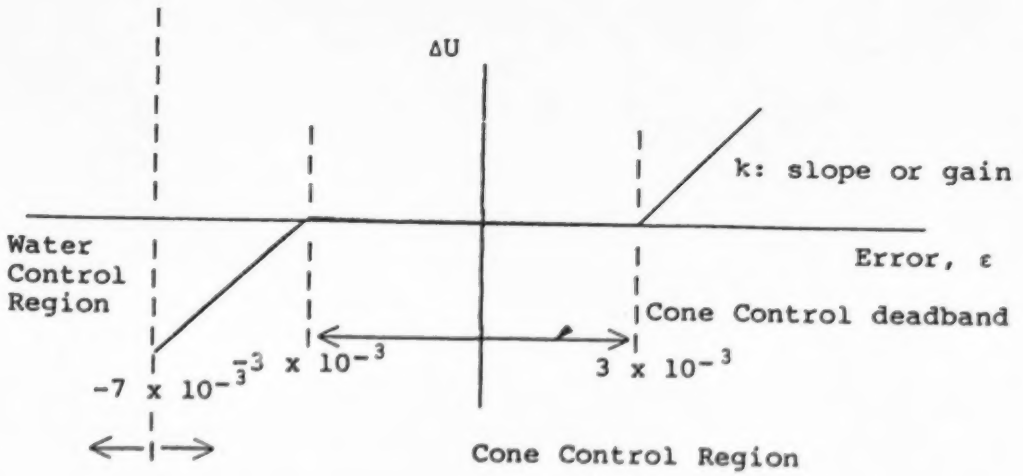


FIGURE 1

HEAVY MEDIUM CONTROL FLOWSHEET

D1336



Definitions:

Error, ε	Density setpoint - Density measured
ΔU	Percentage change in cone control output w.r.t. the equilibrium cone position.
U_C	Current o/p
U_E	Equilibrium cone position

Water Control region: The error region in which water control will take effect.

FIGURE 2
THE CONCEPT OF ZONE CONTROL

D1336

DATAP SYSTEMS

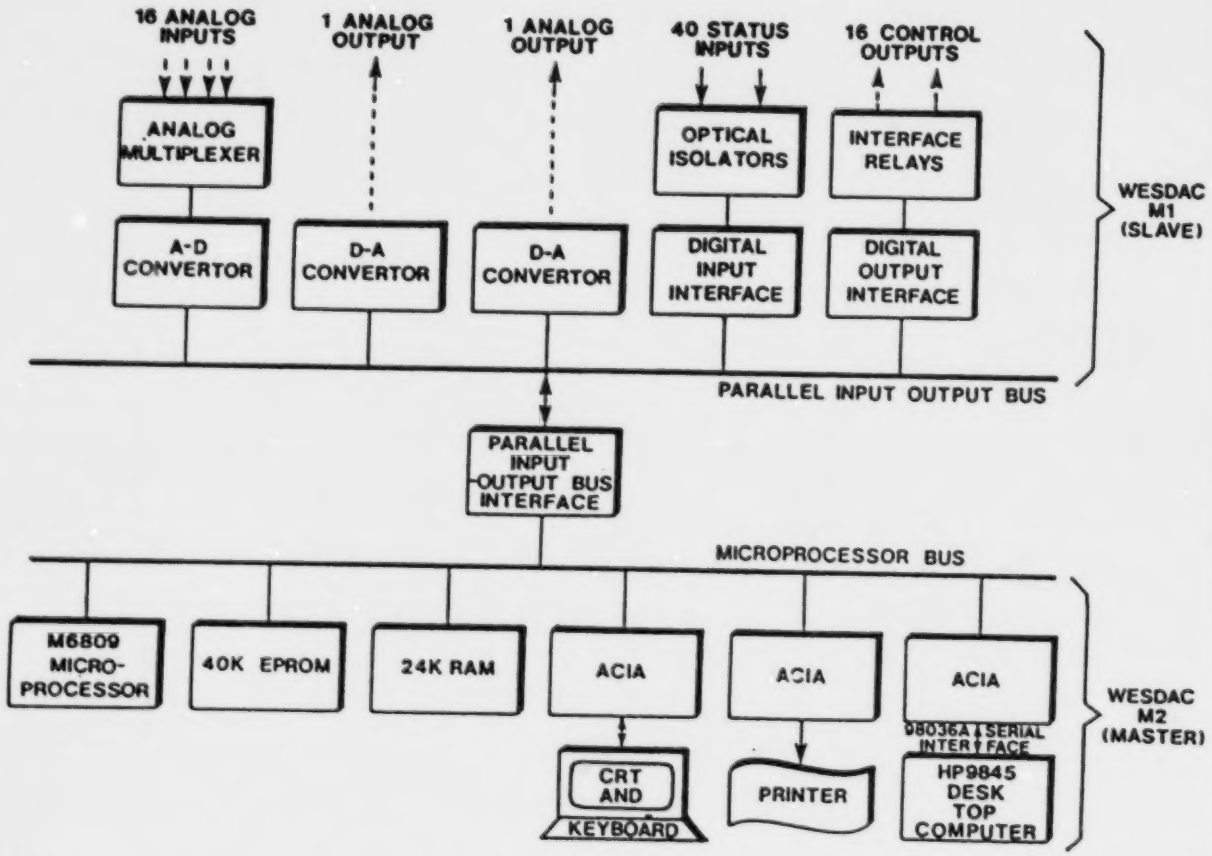


FIGURE 3

COMPUTER SYSTEM STRUCTURE

D1336

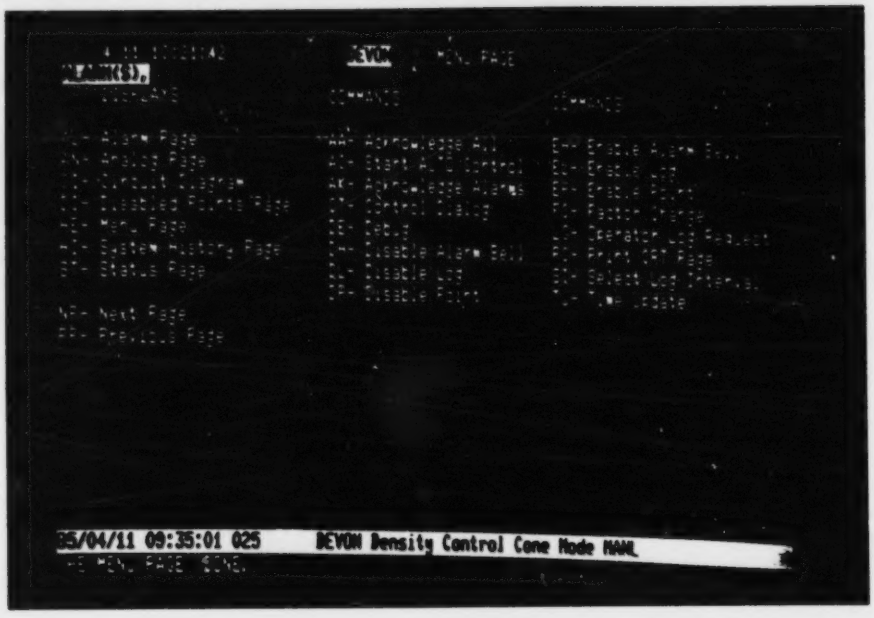


FIGURE 4

MENU PAGE

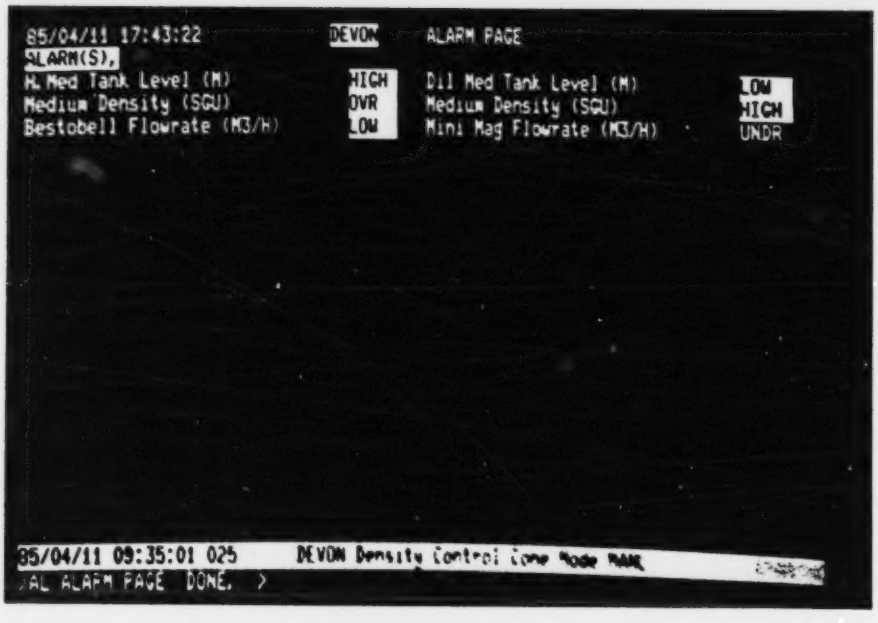


FIGURE 5

ALARM PAGE

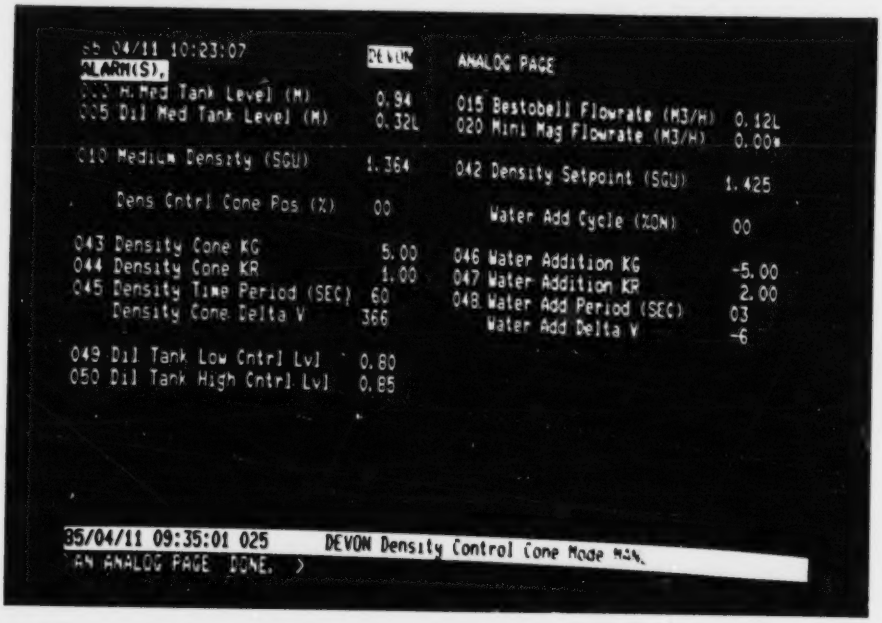

ANALOG PAGE
015 Bestobell Flowrate (M3/H) 0.12L
020 Mini Mag Flowrate (M3/H) 0.00*
042 Density Setpoint (SGU) 1.425
Water Add Cycle (%ON) 00
046 Water Addition KG -5.00
047 Water Addition KR 2.00
048 Water Add Period (SEC) 03
Water Add Delta V -6
010 Medium Density (SGU) 1.364
Dens Cntrl Cone Pos (%) 00
043 Density Cone KG 5.00
044 Density Cone KR 1.00
045 Density Time Period (SEC) 60
Density Cone Delta V 366
049 Dil Tank Low Cntrl Lvl 0.80
050 Dil Tank High Cntrl Lvl 0.85
035 Med Tank Level (M) 0.94
005 Dil Med Tank Level (M) 0.32L
35/04/11 09:35:01 025 DEVON Density Control Cone Mode MAN.
ANALOG PAGE DONE.

FIGURE 6

ANALOG PAGE

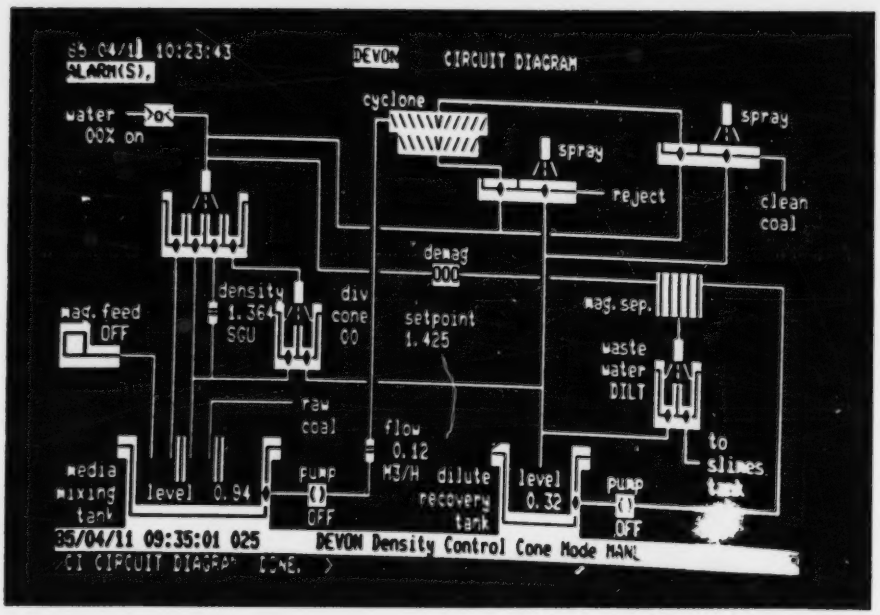


FIGURE 7

CIRCUIT DIAGRAM

D1336

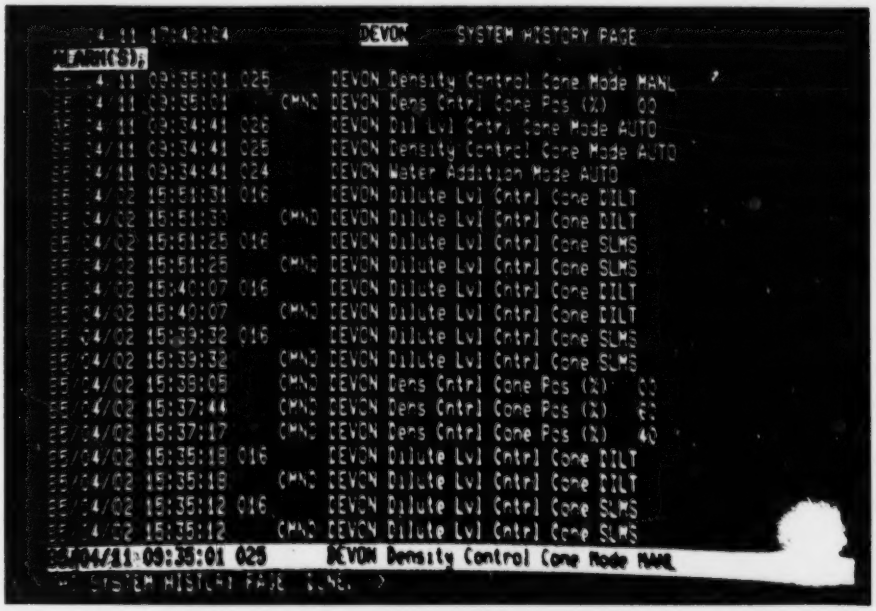

DEVON
SYSTEM HISTORY PAGE
ALARM(S).
DEVON Density Control Cone Mode MANL
DEVON Dens Cntrl Cone Pos (%) 00
DEVON Dil Lvl Cntrl Cone Mode AUTO
DEVON Density Control Cone Mode AUTO
DEVON Water Addition Mode AUTO
DEVON Dilute Lvl Cntrl Cone DILT
DEVON Dilute Lvl Cntrl Cone SLMS
DEVON Dilute Lvl Cntrl Cone DILT
DEVON Dilute Lvl Cntrl Cone SLMS
DEVON Dens Cntrl Cone Pos (%) 00
DEVON Dens Cntrl Cone Pos (%) 60
DEVON Dens Cntrl Cone Pos (%) 40
DEVON Dilute Lvl Cntrl Cone DILT
DEVON Dilute Lvl Cntrl Cone DILT
DEVON Dilute Lvl Cntrl Cone SLMS
DEVON Dilute Lvl Cntrl Cone SLMS
DEVON Density Control Cone Mode MANL

FIGURE 8

SYSTEM HISTORY PAGE

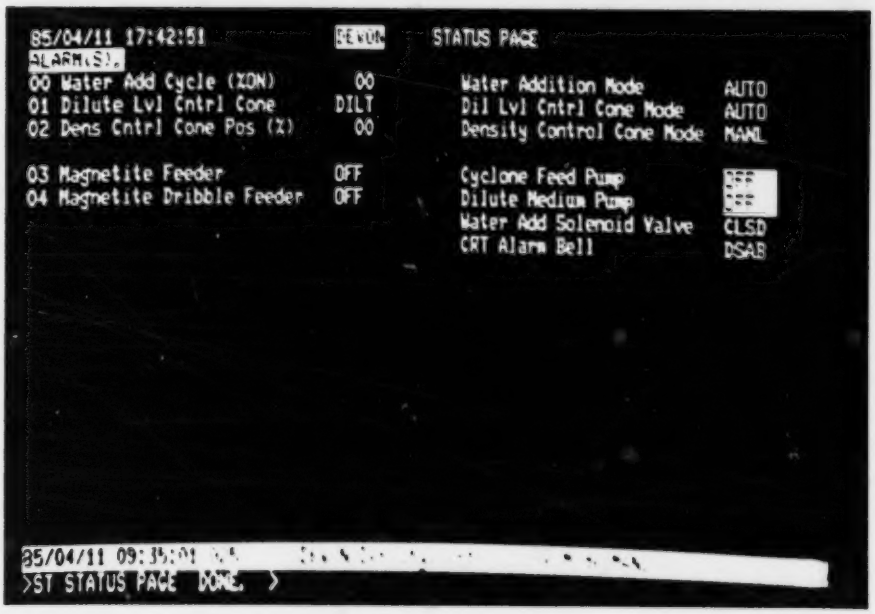
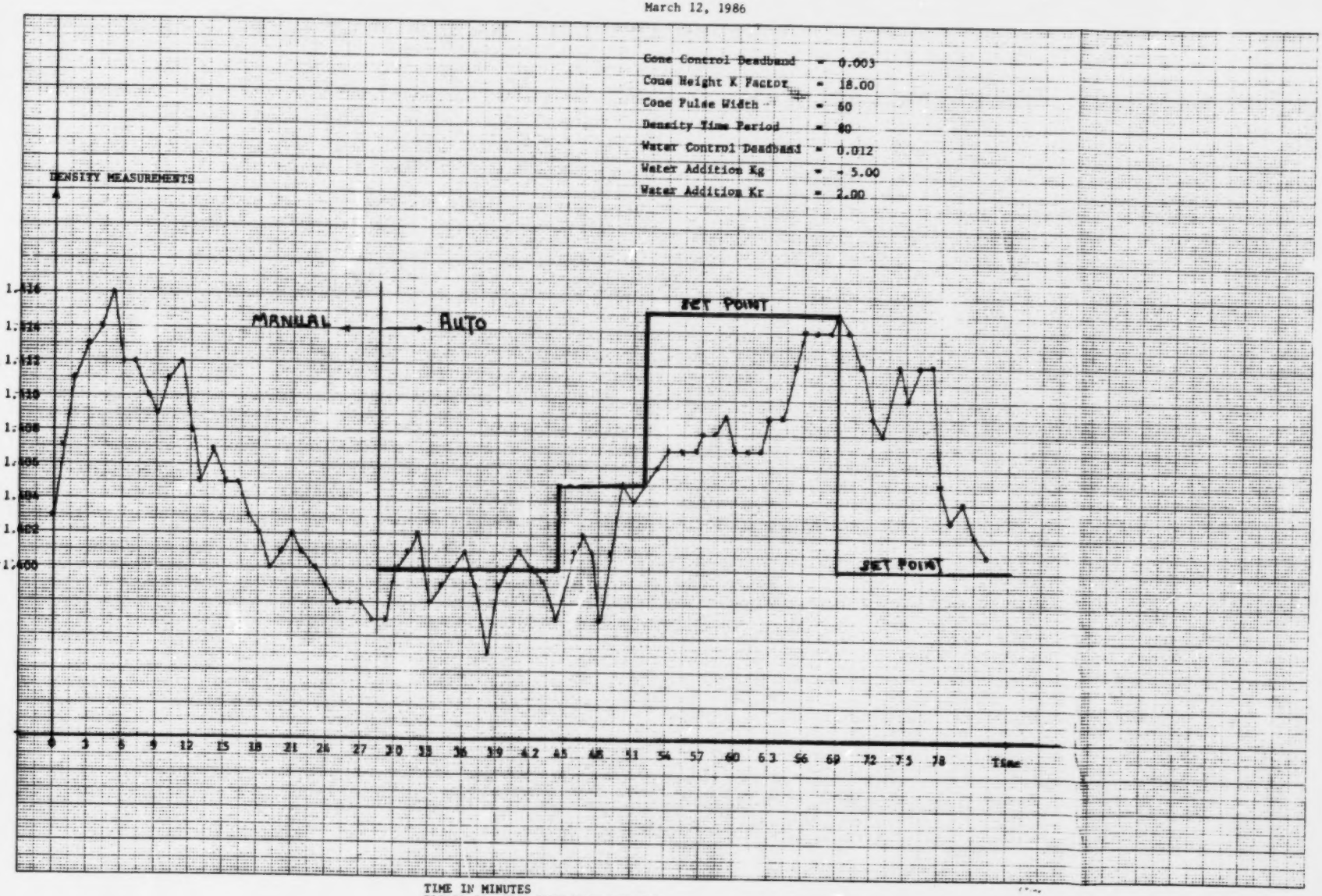

85/04/11 17:42:51
DEVON
STATUS PAGE
ALARM(S).
00 Water Add Cycle (XON) 00
01 Dilute Lvl Cntrl Cone DILT
02 Dens Cntrl Cone Pos (%) 00
03 Magnetite Feeder OFF
04 Magnetite Dribble Feeder OFF
Water Addition Mode AUTO
Dil Lvl Cntrl Cone Mode AUTO
Density Control Cone Mode MANL
Cyclone Feed Pump
Dilute Medium Pump
Water Add Solenoid Valve CLSD
CRT Alarm Bell DSAB
>ST STATUS PAGE DONE. >

FIGURE 9

STATUS PAGE

March 12, 1986



TIME IN MINUTES
FIGURE 10: REAL TIME TEST RESULTS

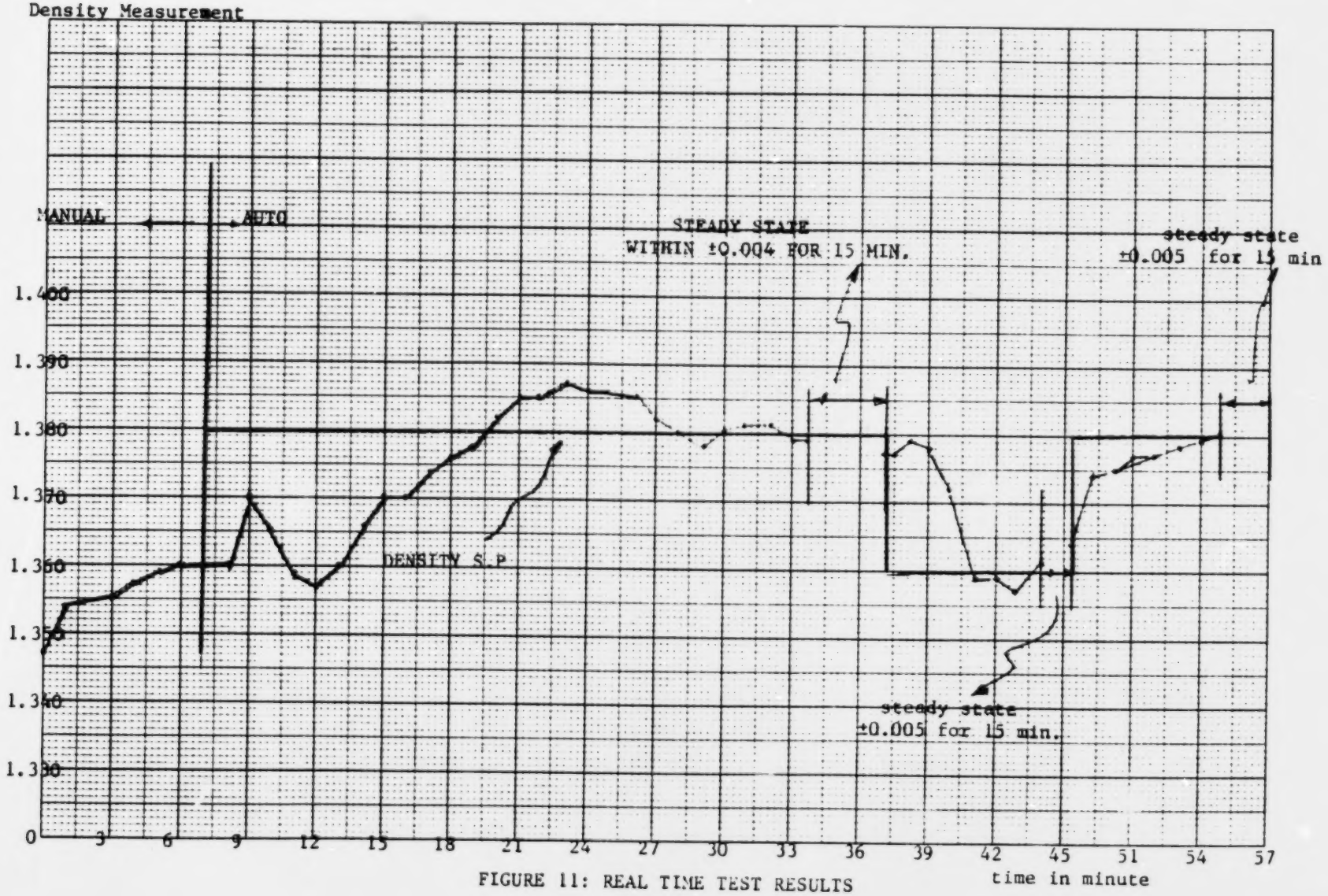


FIGURE 11: REAL TIME TEST RESULTS